



**FREE SPACE OPTICAL and RF COMMUNICATIONS TESTBED
for RESEARCH and EDUCATION in SCALABLE NETWORKS**

Final Report to AFOSR

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SUMMARY

We have procured advanced communications and test equipment to further our research on scalable communication networks, hybrid free-space-optical (FSO)/RF links and networks, and directional links within networks.

DETAILS

The specific major equipment items that we procured under this DURIP program were:

- (1) A Canobeam DT-130-LX FSO communication system operating at 1.24Gb/s over a 1km range
- (2) A Dragonwave "Air-Pair" 24GHz, 100Mb/s directional RF link operating over a range of 1km
- (3) An Agilent E8364B 10MHz to 50GHz Network analyzer and accessories
- (4) A Gigbeam 1.25Gb/s millimiter wave directional communication system
- (5) A Spirent "Smartbits" digital communication link tester
- (6) A NovAtel Real-Time Kinematic GPS System and accessories
- (7) A Pulnix TM-1400CL digital camera
- (8) An Imperx Camera Link Frame Grabber Card
- (9) 2 1550 pigtailed lasers for FSO system
- (10) 1 Personal computer to control the above systems and for data acquisition
- (11) A weather station for monitoring atmospheric conditions on our wireless test ranges.

RESEARCH

The research that has been enabled with the above equipment all fits within our overall research program on reconfigurable, scalable communication networks that use directional laser and RF links. Some of our new research and specific successes that have been made possible with the equipment we have purchased are:

- Implementation of a 1.25Gb/s FSO link over almost 1km across campus.
 - Use of this link for high quality data transfer, especially surveillance vide for event detection.
- Implementation of a 100Mb/s RF link on the same test range as the FSO for side-by-side performance comparisons and tests of weather resistance of FSO and RF directional links.
 - This link also used for tests of HDTV transmission over wireless, and image transfer for event detection.
- Installation of a 1.25Gb/s millimeter wave directional link on our 1km range for side-by-side test against FSO in various weathers.
- Demonstration of the utility of time-delayed diversity for reducing fading on FSO communication links.

- Development of advanced pointing, acquisition, and tracking techniques for FSO and RF directional links mounted on mechanical gimbals.
- The ability to design and test various RF antenna systems for directional wireless communications.

PUBLICATIONS

The research that has been supported by this equipment grant has lead to a significant number of refereed journal articles and conference presentations, including:

- (1) L.M. Wasiczko, I.I. Smolyaninov, and C.C. Davis, "Analysis of compound parabolic concentrators and aperture averaging to mitigate fading on free-space optical links," Proceedings of SPIE, Free-Space Laser Communication and Active Laser Illumination III, vol. 5160, 133-142, 2004.
- (2) Linda Wasiczko, Igor I. Smolyaninov, Stuart D. Milner, and Christopher C. Davis, "Studies of Free Space Optical Links through Simulated Boundary Layer and Long-Path Turbulence," Proceedings of SPIE, vol 5237, 127-135, 2004.
- (3) Jaime Llorca, Aniket Desai, Uzi Vishkin, Christopher Davis, and Stuart Milner, "Reconfigurable Optical Wireless Sensor Networks," the Proceedings of SPIE, vol. 5237, 136-146, 2004.
- (4) Tzung-Hsien (Shawn) Ho, Sugianto Trisno, Igor I. Smolyaninov, Stuart D. Milner, and Christopher C. Davis, "Studies of Pointing, Acquisition, and Tracking of Agile Optical Wireless Transceivers for Free Space Optical Communication Networks," Proceedings of SPIE, vol. 5237, 137-158, 2004.
- (5) S. Trisno, I.I. Smolyaninov, S.D. Milner, and C.C. Davis, "Delayed diversity for fade resistance in optical wireless communication system through simulated turbulence", *Optical Transmission Systems and Equipment for WDM Networking III*, Proc. SPIE 5596, 385-393, 2005
- (6) Clinton L. Edwards and Christopher C. Davis, "Free-Space Optical Communication through a Forest Canopy," to be published in *Applied Optics*.
- (7) Heba Yuksel, Stuart Milner, and Christopher C. Davis, "Aperture averaging for optimizing receiver design and system performance on free-space optical communication links," *Journal of Optical Networking*, 4(8), 462 - 475, 2005
- (8) Stuart D. Milner, Tzung-Hsien Ho, Jaime Llorca, Sugianto Trisno, and Christopher C. Davis, "Self-organizing broadband hybrid wireless networks," *Journal of Optical Networking*, 4(7), 446 - 459, 2005
- (9) L.M. Wasiczko, I.I. Smolyaninov, and C.C. Davis, "Analysis of compound parabolic concentrators and aperture averaging to mitigate fading on free-space optical links," paper presented at the SPIE Conference on Free-Space Laser Communication and Active Laser Illumination III, SPIE 48th Annual Meeting, San Diego, California, 3-8 August, 2003.
- (10) Tzung-Hsien (Shawn) Ho, Sugianto Trisno, Igor I. Smolyaninov, Stuart D. Milner, and Christopher C. Davis, "Studies of Pointing, Acquisition, and Tracking of Agile Optical Wireless Transceivers for Free Space Optical Communication

Networks," paper presented at the Conference on Optics in Atmospheric Propagation and Adaptive Systems VI, SPIE Remote Sensing, Barcelona, Spain, 8-12 September 2003.

(11) Jaime Llorca, Aniket Desai, Uzi Vishkin, Christopher Davis, and Stuart Milner, "Reconfigurable Optical Wireless Sensor Networks," paper presented at the Conference on Optics in Atmospheric Propagation and Adaptive Systems VI, SPIE Remote Sensing, Barcelona, Spain, 8-12 September 2003.

(12) Linda Wasiczko, Igor I. Smolyaninov, Stuart D. Milner, and Christopher C. Davis, "Studies of Free Space Optical Links through Simulated Boundary Layer and Long-Path Turbulence," paper presented at the Conference on Optics in Atmospheric Propagation and Adaptive Systems VI, SPIE Remote Sensing, Barcelona, Spain, 8-12 September 2003.

(13) S. Trisno, I.I. Smolyaninov, S.D. Milner, and C.C. Davis, "Delayed diversity for fade resistance in optical wireless communication system through simulated turbulence", presented at the ITCom 2004 Meeting, October 2004, Philadelphia, PA

(14) Stuart D. Milner and Christopher C. Davis, "Hybrid Free-Space Optical/RF Networks for Tactical Operations," paper presented at MILCOM 2004, Monterey, CA, October 31 - November 3, 2004. Published in the Conference Proceedings, IEEE Catalog Number: 04CH37621C, ISBN:0-7803-8848-8.

(15) Sugianto Trisno, Tzung-Hsien Ho, Stuart D. Milner, and Christopher C. Davis, "Theoretical and Experimental Characterization of Omnidirectional Optical Links for Free Space Optical Communications," paper presented at MILCOM 2004, Monterey, CA, October 31 - November 3, 2004. Published in the Conference Proceedings, IEEE Catalog Number: 04CH37621C, ISBN:0-7803-8848-8.

(16) Heba Yuksel, Christopher C. Davis, and L. Wasiczko, "Aperture averaging experiment for optimizing receiver design and analyzing turbulence on free space optical communication links," paper presented at CLEO 2005, Baltimore, Maryland, May 22-27, 2005

(17) H. Yuksel, W. Atia, and C. C. Davis, "A geometrical optics approach for modeling atmospheric turbulence." Paper present at Conference 5891: Atmospheric Optical Modeling, Measurement, and Simulation, Optics and Photonics 2005, SPIE 50th Annual Meeting, San Diego, California, 31 July - 4 August, 2005

(18) J. Llorca, A. Desai, S.D. Milner, and C.C. Davis, "Optimizing performance of hybrid FSO/RF networks in realistic dynamic scenarios," paper presented at Conference 5892: Free-Space Laser Communications V, Optics and Photonics 2005, SPIE 50th Annual Meeting, San Diego, California, 31 July - 4 August, 2005

(19) H. Yuksel and C.C. Davis, "Aperture averaging for studies of atmospheric turbulence and optimization of free-space optical communication links," paper presented at Conference 5892: Free-Space Laser Communications V, Optics and Photonics 2005, SPIE 50th Annual Meeting, San Diego, California, 31 July - 4 August, 2005

(20) S. Trisno, I.I. Smolyaninov, S.D. Milner, and C.C. Davis, "Characterization of delayed diversity optical wireless system to mitigate atmospheric turbulence

induced fading," paper presented at Conference 5892: Free-Space Laser Communications V, Optics and Photonics 2005, SPIE 50th Annual Meeting, San Diego, California, 31 July - 4 August, 2005

(21) T. Ho, S.D. Milner, and C.C. Davis, "Pointing, acquisition, and tracking system with omnivision for free-space optical communication networks, paper presented at Conference 5892: Free-Space Laser Communications V, Optics and Photonics 2005, SPIE 50th Annual Meeting, San Diego, California, 31 July - 4 August, 2005

(22) Tzung-Hsien Ho, Stuart D. Milner, and Christopher C. Davis, "Using Geometric Constraints for Fisheye Camera Calibration," paper presented at the International Conference on Computer Vision, Beijing, China, October 17-20, 2005

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